UNIVERSITY OF TECHNOLOGY SYDNEY

COUPLED TANKS GENERATION II RIG LABORATORY USER GUIDE

VERSION 1.4

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Revision History

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1 Introduction

1.1 Remote Laboratories

Remote laboratories enable students to access physical laboratory apparatus through the internet, providing a supplement to their studies and existing hands-on experience. Students carry out experiments using *real* equipment, but with much greater flexibility since access can occur from anywhere and at any time. Their interaction with the remote equipment is assisted by the use of data acquisition instrumentation and cameras, providing direct feedback to students for better engagement.

Traditional engineering laboratories require students to be physically present in order to work with equipment, which may limit student flexibility. Conversely, remote laboratories let students work in their own time and even repeat experiments for better learning outcomes.

Of course students cannot actually touch and feel the equipment in a remote laboratory, but they can still perform most other tasks relevant to their learning. Sometimes, separation from potentially hazardous equipment is preferable from a safety point of view.

Due to the increased use of remote operation in industry, where machinery and entire plants are often controlled from a distant location, students may directly benefit from learning how to remotely control equipment. Furthermore, remote laboratories provide the opportunity to access a wider range of experiments as costly or highly specialised equipment may not be locally available. This presents the opportunity to share laboratory facilities between institutions.

Significant research and pilot studies have been undertaken in Australia and by several groups around the world into the educational effectiveness of using remote laboratories. These studies have consistently shown that, if used appropriately in a way that is cognizant of the intended educational outcomes of the laboratory experience, remote laboratories can provide significant benefits.

Indeed, multiple research studies have demonstrated that whilst there are some learning outcomes that are achieved more effectively through hands-on experimentation (e.g. identification of assumptions, specific haptic skills), there are other learning outcomes that are achieved more effectively through remotely accessed laboratories (e.g. processing of data, understanding of concepts).

Engineering students are able to access the Coupled Tanks Generation II Rigs to help them develop and verify their mathematical models of the complex system dynamics involved in a SISO/MIMO coupled tank system. The Coupled Tanks Generation II allows students to:

- Characterise the behaviour of a Single Input Single Output (SISO) or Multi Input Multi Output (MIMO) coupled tank system.
    - **Note:** As of mid- 2012, the Coupled Tanks Generation II Rig is only capable of running in SISO mode as MIMO functionality requires hardware that is not yet implemented into the system.
- Acquire experimental data to assist in developing a simplified model of the system.
- Implement a PID controller to manage the inlet flow rate of water, such that the water level in the desired tank is kept constant.

1.2 Coupled Tanks Generation II - The Rig Apparatus

The Coupled Tanks Generation II Rig was designed to allow students to acquire data from a physical dynamic system in order to develop a simplified mathematical model of the underlying dynamics.

Once the mathematical models have been developed, students are able to design a control system using a P, PI, PD or PID controller and analyse the performance of the controller in maintaining the water level in one of the two tanks. The rigs emulate a process engineering scenario whereby it may be critical to maintain a specific fluid level in a tank with single or multiple input(s) and output(s) acting upon the system, allowing students to characterise the behaviour of such systems.

Each Coupled Tanks Generation II Rig consists of the following main components:

- 1 x Frame
- 2 x Tanks
  - *1 x Primary Tank*
  - *1 x Secondary Tank*
- 1 x Reservoir
- 2 x Pumps
- 6 x Flow Meters
  - *2 x Inlet Flow Meters*
  - *2 x Outlet Flow Meters*
  - *2 x Inter-Tank Flow Meters*
- 2 x Control Valves
- 2 x Inter-Tank Coupling Valves
- 2 x Level Sensors with Magnetic Floats

Additionally, each Coupled Tanks Generation II Rig is monitored by a web camera so as to provide real-time video of the system. The entire suite of Rigs is controlled by a Real-Time I/O controller which enables data acquisition and control of the components within each Rig. The control interface is written in LabVIEW.

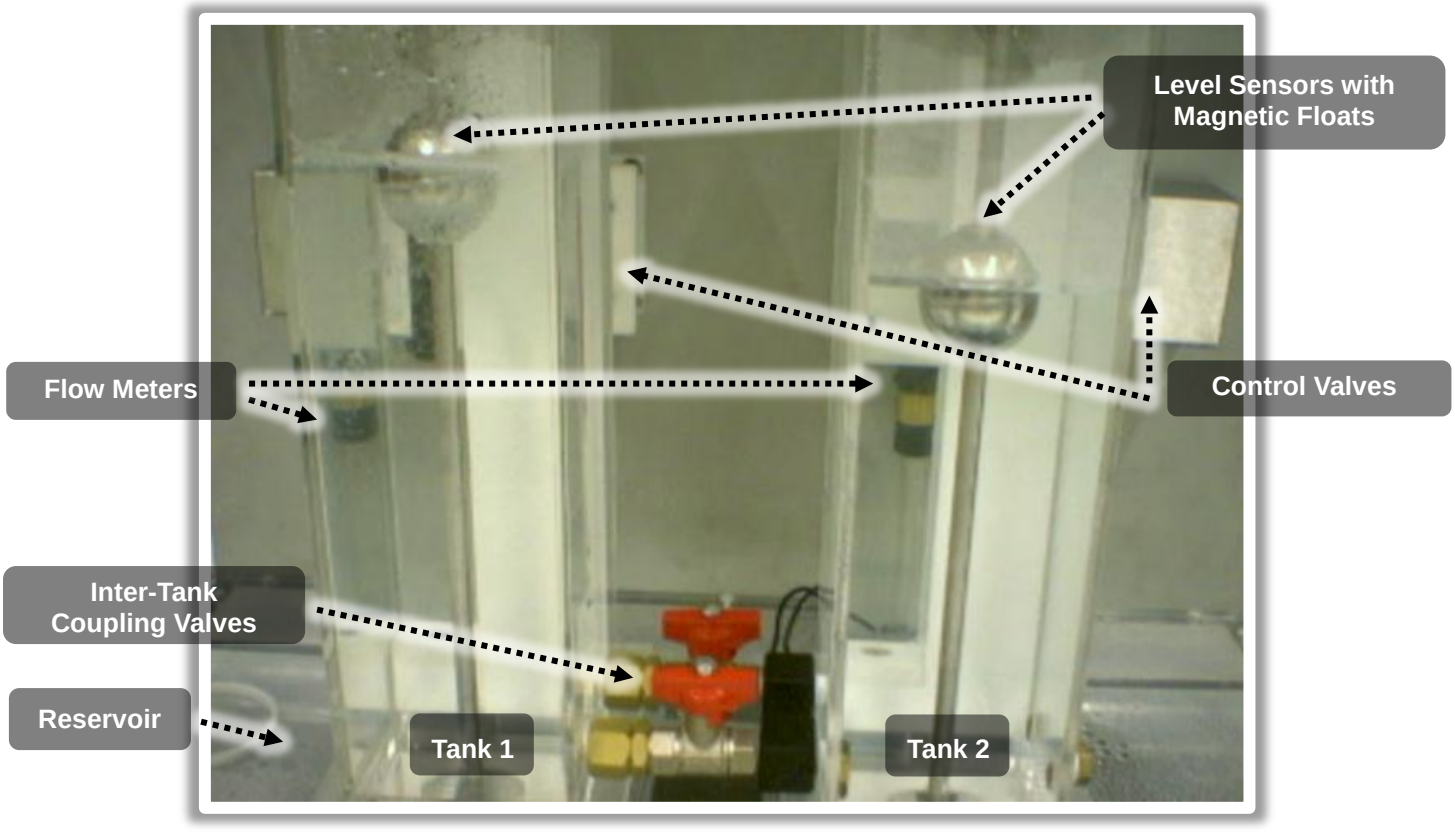


Figure 1: Coupled Tanks Generation II Rig.

2 Rig Specifications

2.1 Frame

The rig frame is made of MayTec Aluminium Extrusion with a 40mm profile. The frame has a 6 mm thick aluminium base-plate to support the reservoir and the tanks. An additional circular cut-out allows for access to the reservoir drain plug during system maintenance. The back-plate is made from 6 mm thick aluminium and has been CNC machined with numerous chamfered through-holes for component wiring.

2.2 Tanks

The tanks are made of a mixture of 6mm and 3mm acrylic. Each tank has a recess for the level sensors and a stepped outlet so as to compensate for the "dead-zone" of each sensor. The tank also has an internal overflow outlet to ensure that the water level does not exceed the design allowance of 295 mm (± 2.5 mm). The tanks have a capacity of approximately 3,800 cc (3.8 L) each.

2.3 Reservoir

The reservoir acts as a common water supply for the system, supplying both pumps and has a capacity of approximately 17,500 cc (17.5 L). The reservoir has been designed such that even with both tanks operating at maximum level, sufficient water level (head) is provided above the pump inlet to avoid the formation of inlet vortices and the consequential effects of air-ingestion, such as cavitation.

2.4 Pumps

The pumps are Swiftech MCP-35X branded units, which are re-badged Laing Thermotech DDCs utilising a DDC3.1-PWM PCB (Printed-Circuit-Board). The MCP-35X is an electronically commutated spherical motor pump. The only moving part in the unit is the permanent-magnet spherical impeller and this is supported by a ball-shaped ceramic bearing.

The implementation of such a bearing effectively eliminates bearing play and any associated noise increase and ensures that the bearing is self-realigning. The internal components are lubricated directly by the media being pumped (known as a wet-rotor design).

The permanent-magnetic impeller is driven by a stator – built into the pump housing - that wraps a magnetic field around the impeller, as this field is switched on and off, the impeller rotates. The MCP-35X features RPM (tachometer) output as well as PWM (Pulse-Width-Modulation) speed control input. Specifications are given below:

Pump Specifications	
Manufacturer:	Swiftech / Laing Thermotech
Model Number:	MCP-35X / DDC3.1-PWM.
Motor type:	Electronically Commutated, Brushless DC, Spherical Motor
Bearing Type:	Spherical Ceramic Ball
Operating RPM:	1,300 – 4,500 (via PWM)
Operating Voltage Range:	9 – 13.4 VDC
Nominal Voltage:	12 VDC
Max. Nominal Current Draw @ 12 VDC:	1.5 A
Max. Nominal Power Draw @ 12 VDC:	18 W
Max. Nominal Head @ 12 VDC:	4.4 mH_2O
Max. Nominal Flow Rate @ 12 VDC:	0.292 L/s (17.5 L/min)
RPM Signal:	Open Collector 20mA, 0-24 VDC Square Wave 2 pulses per revolution
PWM Signal:	5V DC, 20-25 kHz
Fittings:	G¼" BSPP Female Threaded Inlet & Outlet

2.5 Flow Meters

The flow meters are Parker DataFlow Compact DFC9000100 units. These are in-line impeller-type units that output a pulse as the impeller revolves in the fluid flow. They do this by shining an infra-red beam perpendicular to the axis of rotation of the impeller through to a sensor, creating what is known as a photo-interrupter.

As the impeller spins, it interrupts the beam, creating a "pulse" in the output voltage. The on-board circuitry has been designed such that this output voltage is a square wave. The manufacturer provides a typical "K-factor" for calibration that states how many pulses equate to a given flow rate. The units are equipped with G3/8" BSPP male-threaded connectors and have an internal diameter of approximately 10mm. Specifications are given below:

Flow Meter Specifications	
Manufacturer:	Parker Hannifin
Model Number:	DataFlow Compact DFC9000100
Flow Meter Type:	In-line, impeller-type
Operating Voltage:	5 VDC
Operating Range:	1-25 L/min
Pressure Drop:	1 mH_2O @ 15 L/min
K-Factor:	752 pulses per Litre (Typical)
Accuracy:	± 2% (Typical)
Repeatability:	± 1%
Output Signal:	5V DC Square Wave
Fittings:	G3/8" BSPP Male Threaded Inlet & Outlet

2.6 Control Valves

The control valves are a hybrid unit, consisting of a Hass Manufacturing EPV-375B Electronic Proportional Valve and a Leadshine DM422C Digital Stepper Motor Controller.

The EPV-375B is a brass-bodied in-line globe valve with ½" NPT female threaded inlet & outlet. The valve is actuated by a Moons 5618S-05D stepper motor connected to the valve stem. The ND556 is a high performance stepper motor controller using pure-sinusoidal current control and allows a variety of settings such as motor current and micro-step resolution to be programmed via DIP switches.

Specifications for this hybrid unit are given below:

Control Valve Specifications	
➢ **Valve**	
Manufacturer:	Hass Manufacturing
Model Number:	EPV-375B
Valve Type:	In-line Globe
Material:	Brass
Flow Factor (K_v):	1.47 (m^3/hr with ΔP 10 mH_2O)
Actuation:	Moons 5618S-05D Stepper Motor, NEMA Size 23, 1.8° Full Step Angle, 29Ω/Phase, 0.42Nm
Fittings:	½" NPT Female Threaded Inlet & Outlet
➢ **Control**	
Manufacturer:	Leadshine
Model Number:	ND556
Operating Voltage:	24 VDC
Steps per Revolution:	800 (programmed)
Motor Peak Current:	1.4 A (programmed)

2.7 Inter-Tank Coupling Valves

The tanks are coupled with a pair of fullway ball valves made by Giacomo Cimberio S.P.A. These valves have a G3/8" BSPP female threaded inlet & outlet, Teflon stem and ball gaskets and a hot forged brass ball and body.

To aid in maintenance of the system, UTS developed custom push-fit connectors which attach the valves to the tanks. The push-fit connectors use a double o-ring system, which allows for easy removal of the coupling valves for maintenance, inspection & replacement. The specifications for the coupling valves are given below:

Coupling Valve Specifications	
Manufacturer:	Giacomo Cimberio S.P.A
Model Number:	CIM312
Valve Type:	Fullway Ball Valve, Butterfly Handle
Ball & Body Material:	Hot Forged Brass
Stem & Ball Gasket Material:	Teflon (P.T.F.E)
Flow Factor (K_v):	10 (m^3/hr with ΔP 10 mH_2O)
Fittings:	G3/8" BSPP Female Threaded Inlet & Outlet

2.8 Level Sensors with Magnetic Floats

The level sensors used are MTS Temposonics GH Rod-Style magnetostrictive position sensors. These sensors use the principle of magnetostriction - a phenomena that causes a material to change shape during magnetisation.

To allow the sensor to measure a level or distance, an external magnet located at some position along the wave guide, generates its own magnetic field within that vicinity. The sensor sends a current pulse along the wave guide and when the current pulse reaches the position of the external magnet, the two magnetic fields interact, producing a strain pulse.

It is the time between the current pulse and this returning strain pulse that is measured by the sensor and then converted into an output signal that corresponds with distance.

The sensors used here output a 4-20 mA current signal to the real time I/O controller, allowing for accurate and fast measurements. To allow for measurement of the fluid level in the couple tanks – a magnetic float is used to provide the required external magnetic field to interact with the current pulse. Specifications for the level sensors are provided below:

Level Sensor Specifications	
Manufacturer:	MTS
Model Number:	Temposonics GH Rod-Style Magnetostrictive Sensor
Rod Material:	304L Stainless Steel
Magnet Type:	Magnetic Float
Supply Voltage:	24 VDC
Update Time:	<1ms (Typical)
Resolution:	Infinite (Restricted by output ripple)
Non-Linearity:	< ±0.02% Full Stroke (± 50 µm min.)
Repeatability:	< ±0.001% Full Stroke (± 2.5 µm min.)
Signal Output:	4-20 mA
Stroke:	300mm
Dead Zones:	51mm from Flat-Faced Flange, 63.5mm from Rod End

2.9 Real Time I/O Controller

The Coupled Tanks Generation II Rig is controlled by a National Instruments Compact Real-Time I/O Controller, aka cRIO. The cRIO chosen - a cRIO-9022 - has a 533MHz controller with 2GB storage, 256MB DDR2 RAM, USB/RS232 interfaces and dual Ethernet ports.

For I/O, the chassis - a cRIO-9114 with embedded Xilinx Virtex-5 FPGA - has 4x NI 9403 32-Ch, 5 V/TTL, 7µS Bidirectional Digital I/O Modules installed as well as 1x NI 9208 16-Ch, ±20mA, 16-Bit, 200kS/s Current Input Module.

Interfacing to each rig is performed via a custom PCB designed at UTS that re-routes the I/O lines from the DB37 connector on each I/O module to a DB25 connector for each rig. This then simply connects via a standard DB25 cable – providing a complete and simplified I/O solution. The use of digital I/O and current (rather than voltage) based sensors reduces the amount of noise and signal degradation in the rig.

Control of the rig is performed through a LabVIEW application that communicates with the cRIO, presenting the user with accurate, real-time information and control of each rig.

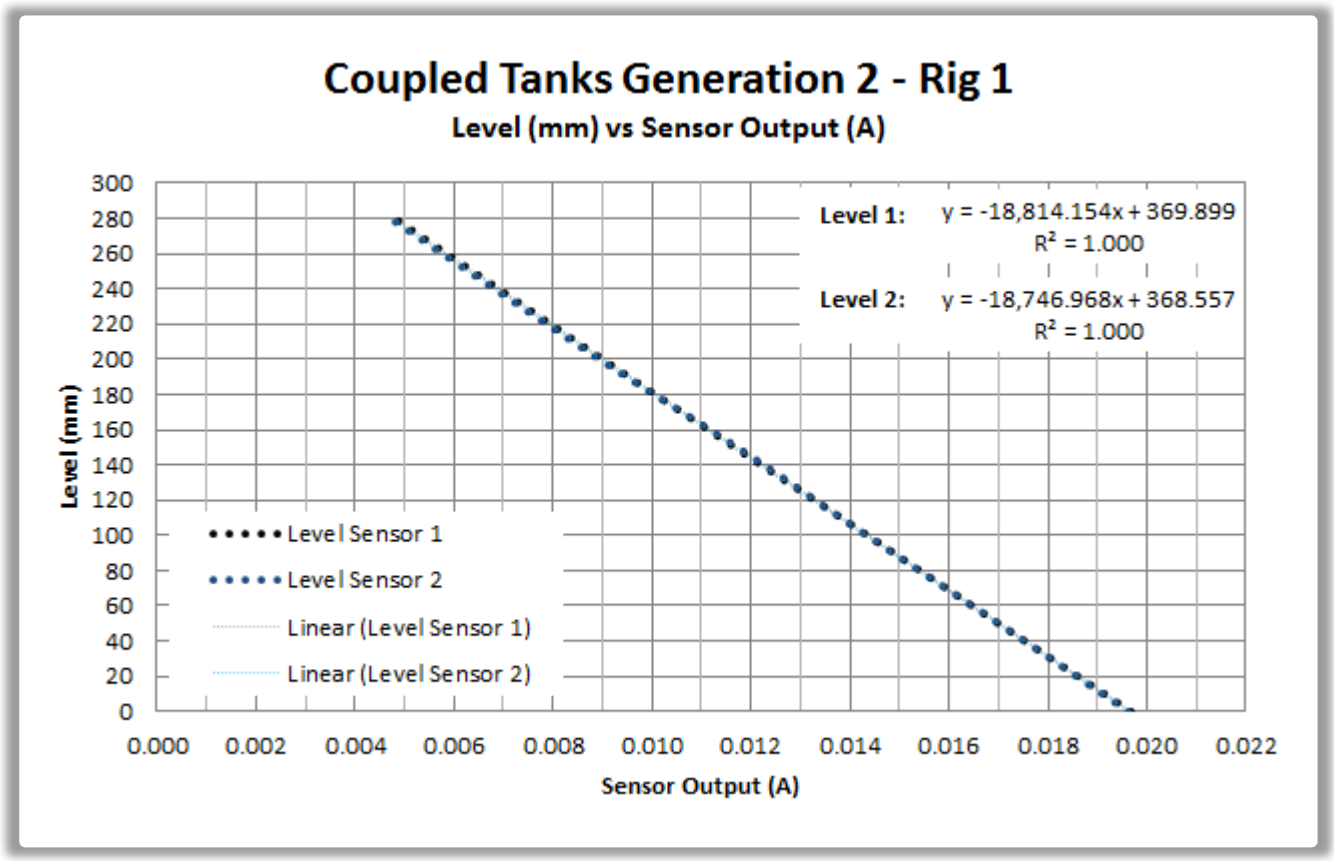
Real Time I/O Controller Specifications	
Manufacturer:	National Instruments (NI)
Controller:	NI cRIO-9022 Real-Time I/O Controller
Chassis:	NI cRIO-9114
Controller Specifications:	533MHz controller with 2GB storage, 256MB DDR2 RAM
Chassis Specifications:	8-slot Virtex-5 LX 50 Reconfigurable Chassis
I/O Modules:	4 x NI 9403 32-Ch, 5 V/TTL, 7µS Bidirectional Digital I/O Modules 1 x NI 9208 16-Ch, ±20mA, 16-Bit, 200kS/s Current Input Module

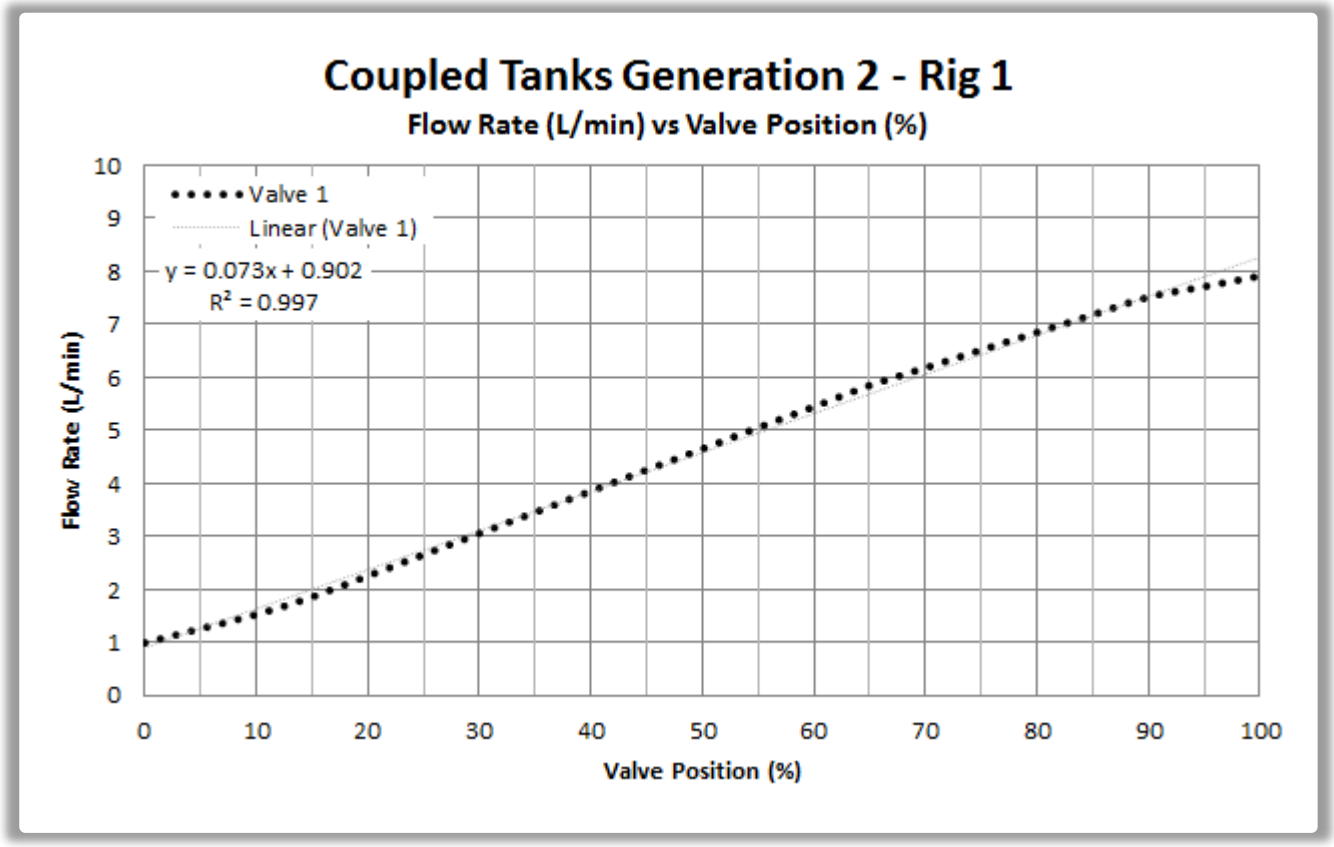
2.10 More Information

A specification pack containing more information on the hardware used will be released at a later date as a downloadable archive (.zip) file located on the session page for each rig.

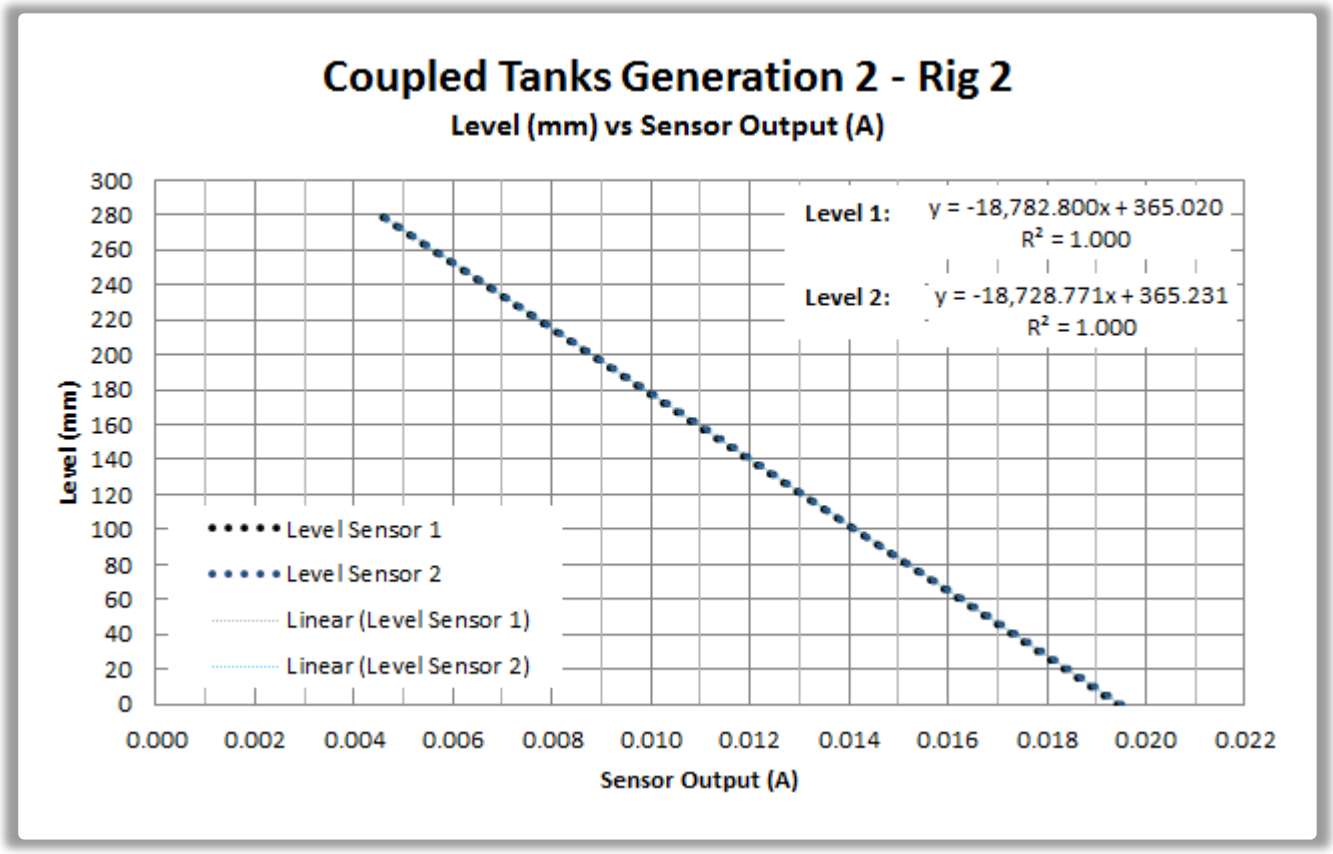
3 Calibration Data

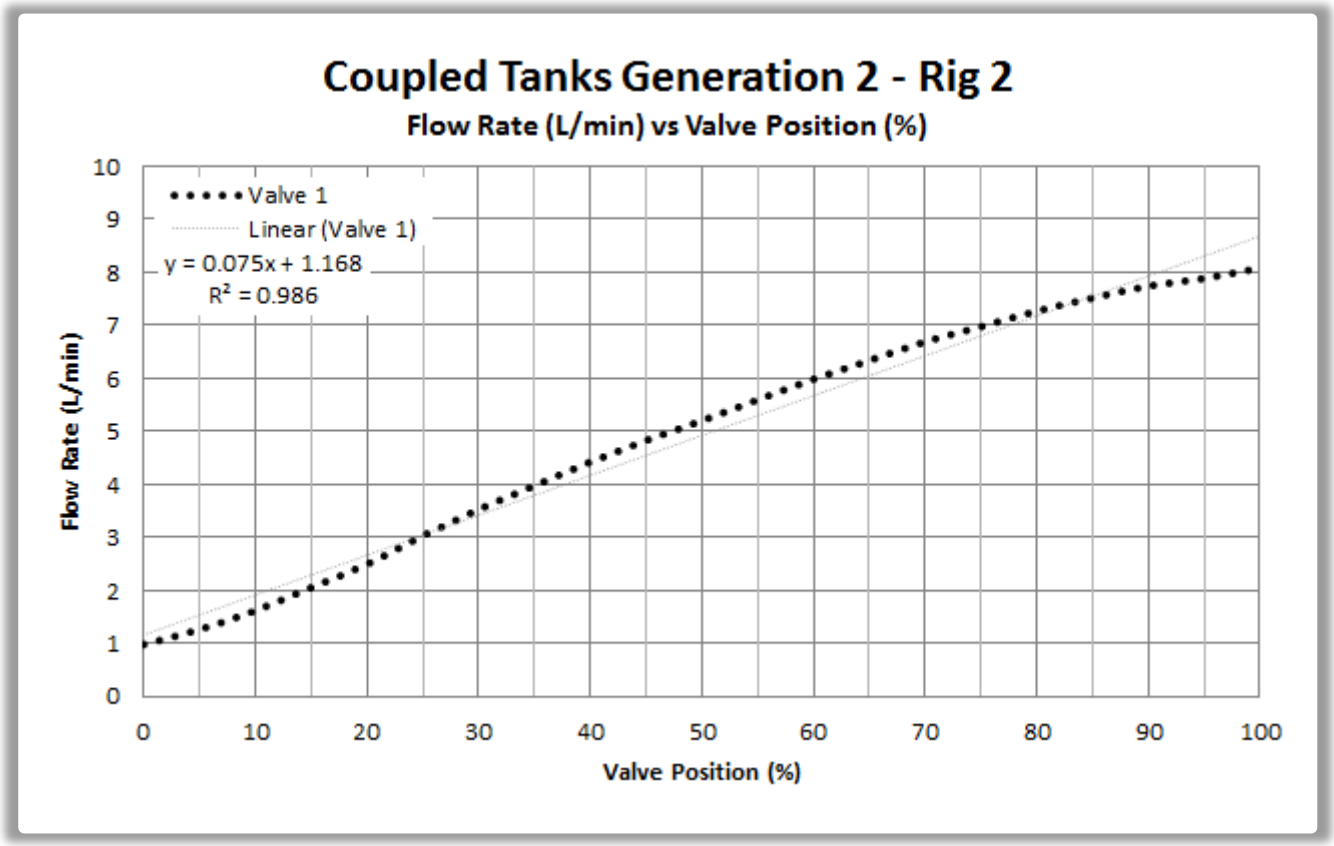
3.1 Rig 1





3.2 Rig 2


Coupled Tanks Generation 2 - Rig 2
Level (mm) vs Sensor Output (A)
Level 1: y = -18,782.800x + 365.020
R² = 1.000
Level 2: y = -18,728.771x + 365.231
R² = 1.000
Level (mm)
Sensor Output (A)
Level Sensor 1
Level Sensor 2
Linear (Level Sensor 1)
Linear (Level Sensor 2)


Coupled Tanks Generation 2 - Rig 2
Flow Rate (L/min) vs Valve Position (%)
Valve 1
Linear (Valve 1)
y = 0.075x + 1.168
R² = 0.986
Flow Rate (L/min)
Valve Position (%)

4 Rig Control Software

After clicking the “launch” button – you should be presented with the rig control software. This is a LabVIEW application that allows you to control the valve position / inlet flow rate, observe the inlet, inter-tank and outlet flow rates and implement a PID controller for level control of the secondary tank.

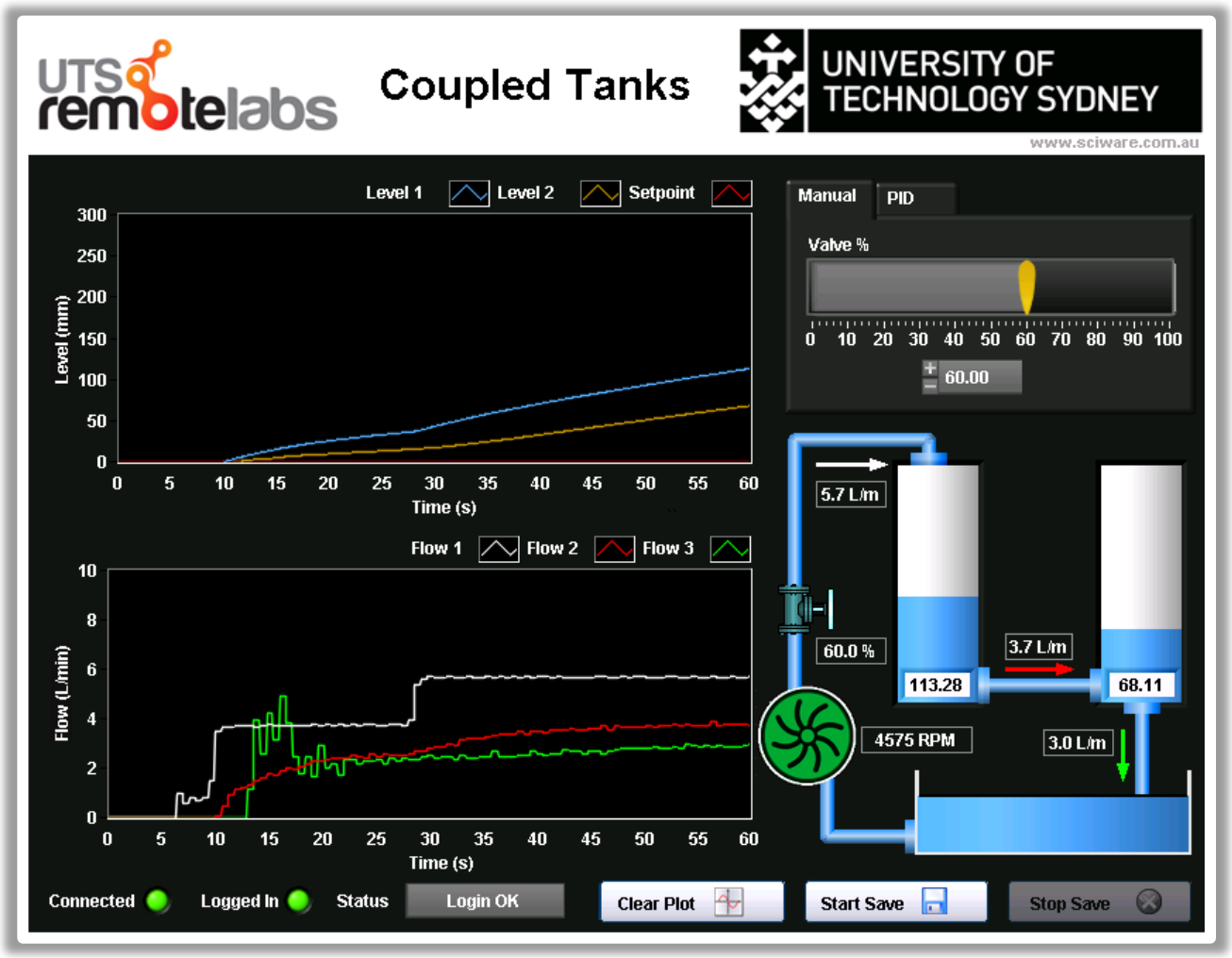


Figure 2: *Rig Control Software with the system operating in Open-Loop Mode.*

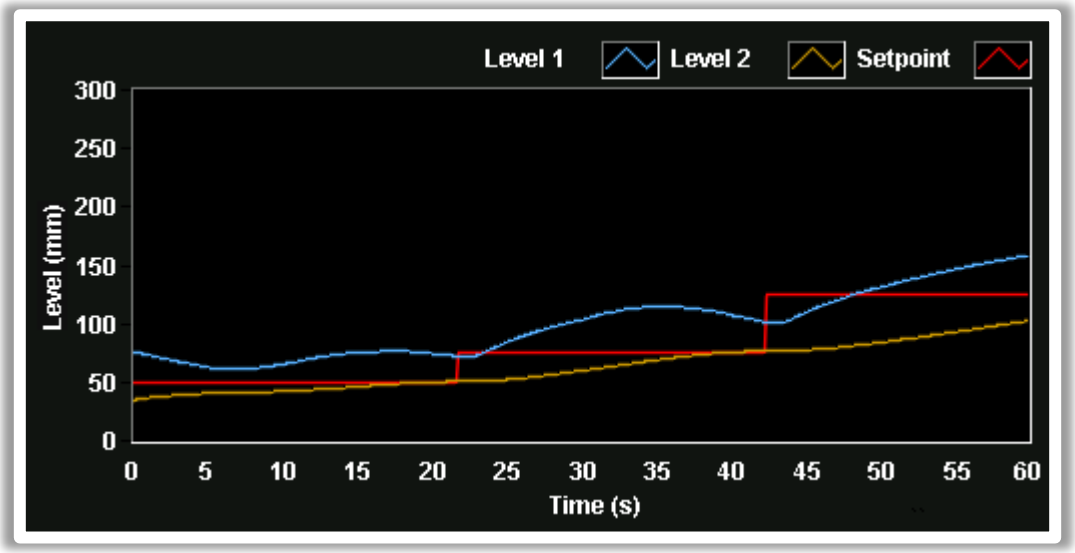
4.1 Data Display

The rig control software displays numerous sources of data in real-time. Familiarise yourself with the display and relevance of this data by reading through the sections below.

Please be aware of hardware limitations that are outlined in section **"6.1 Hardware Limitations"** of this document before reporting any faults with the rig from data shown on the displays described below.

4.1.1 Water Level Plot

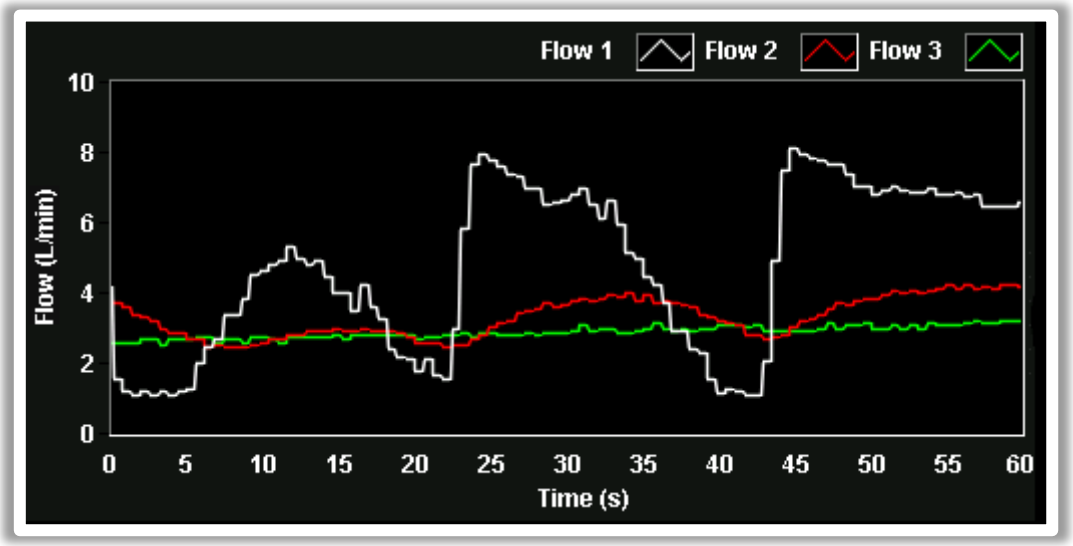
In both Manual and PID modes, the water level is displayed for Tank 1 and Tank 2 in real-time with units of millimetres. The tank is empty at 0 mm (± 0.5 mm) and reaches overflow at 295 mm (± 5 mm).



Tank 1 has the label "Level 1" and is shown in Blue. Tank 2 has the label "Level 2" and is shown in Orange. In PID mode only, the desired level for Tank 2 has the label "Setpoint" and is shown in Red.

4.1.2 Flow Rate Plot

In both Manual and PID modes, the flow rates for different points in the system are displayed in real-time with units of Litres per Minute (L/min). Three different flow rates are given for the system – Flow 1, Flow 2 and Flow 3.

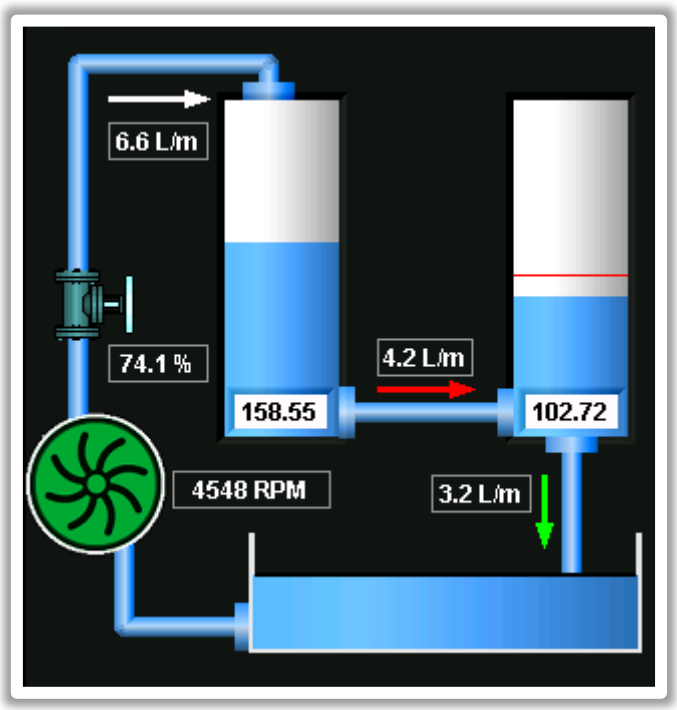


Flow 1 is shown in White, Flow 2 is shown in Red and Flow 3 is shown in Green. These flow rates correspond to the Inlet Flow Rate (Tank 1), the Inter-Tank Flow Rate and the Outlet Flow Rate (Tank 2) respectively.

4.1.3 System Overview Animation

In addition to the plots noted previously, an animation of the system with instantaneous display of important data is provided.

The level of each tank is illustrated and the instantaneous level can be observed by looking at the corresponding numerical readout shown on each tank. Additionally, the instantaneous inlet flow rate, inter-tank flow rate and outlet flow rates are shown.



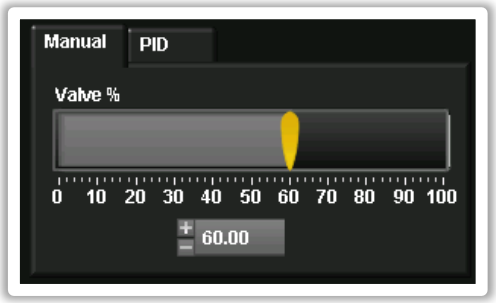
The current valve position as a percentage is displayed next to the valve. The Pump status is indicated by the colour surrounding the impeller (green for ON, red for OFF), with the impeller speed displayed in RPM to the right. Finally, the setpoint for the desired level for Tank 2 is indicated by the red line.

4.1 Open-Loop Control

The Coupled Tanks Generation II Rig has two operating modes. The first is Open Loop (Manual) mode, whereby the user controls the valve position and consequently the inlet flow rate directly.

4.1.1 Valve Position / Inlet Flow Rate

As noted above, in this mode, the valve position and hence the inlet flow rate is adjustable by the user. You can either type in a value in the input box with up to 2 decimal points of precision and press enter to set it or drag the yellow slider to your desired position, or adjust the position with increments of ±1% from the current position by pressing the buttons next to the input box.



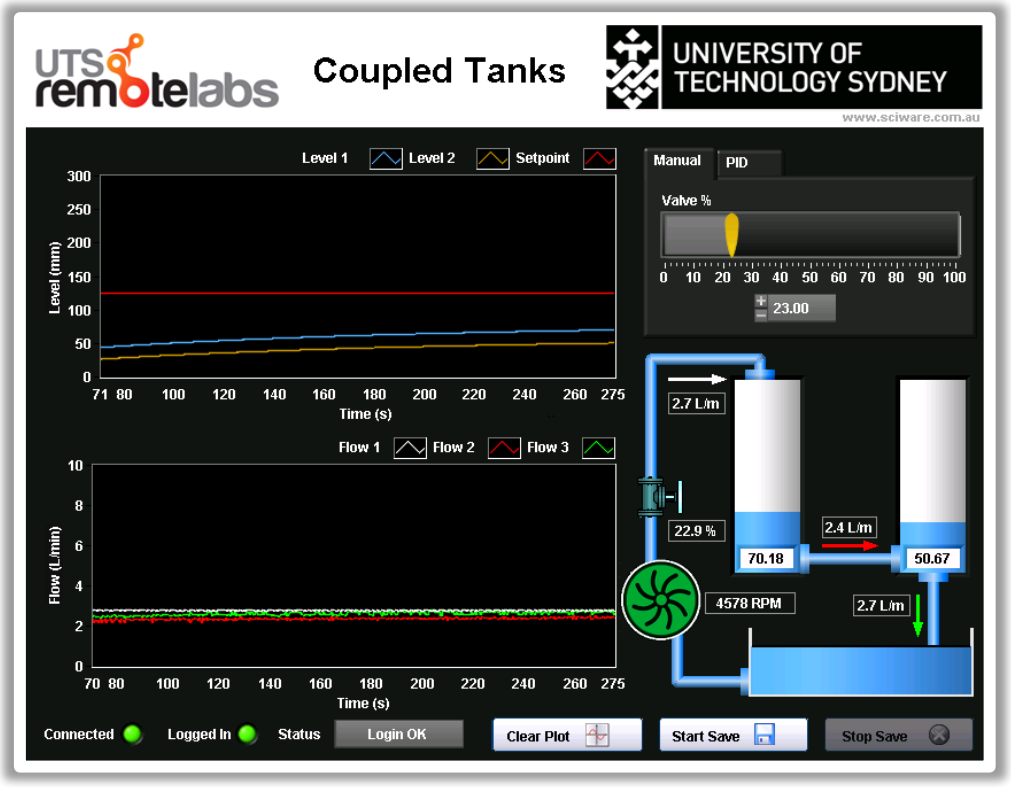
Note: The inlet flow rate is always non-zero, this is by design. See section **6.1.1**for more information.

4.1.2 Open-Loop States

By setting a constant inlet flow rate, the tanks will eventually reach one of two states.

The first is “steady state”, whereby the inlet flow rate, inter-tank flow rate and outlet flow rates are matched, with the system balancing out at a specific level for each tank. In these scenarios, the response of the system can be measured and included in dynamic models.

The second is that of “overflow”, whereby the inlet flow rate is set too high and the system cannot balance itself (see **6.1 Hardware Limitations** for further explanation) – as a result, the level in Tank 1 reaches a maximum and excess water goes into the tank overflow outlet. In this case, the response of the system cannot be measured.



Above: The system *approaching* steady state. Note the flow rates converging and the levels flattening out.

4.2 Closed-Loop Control

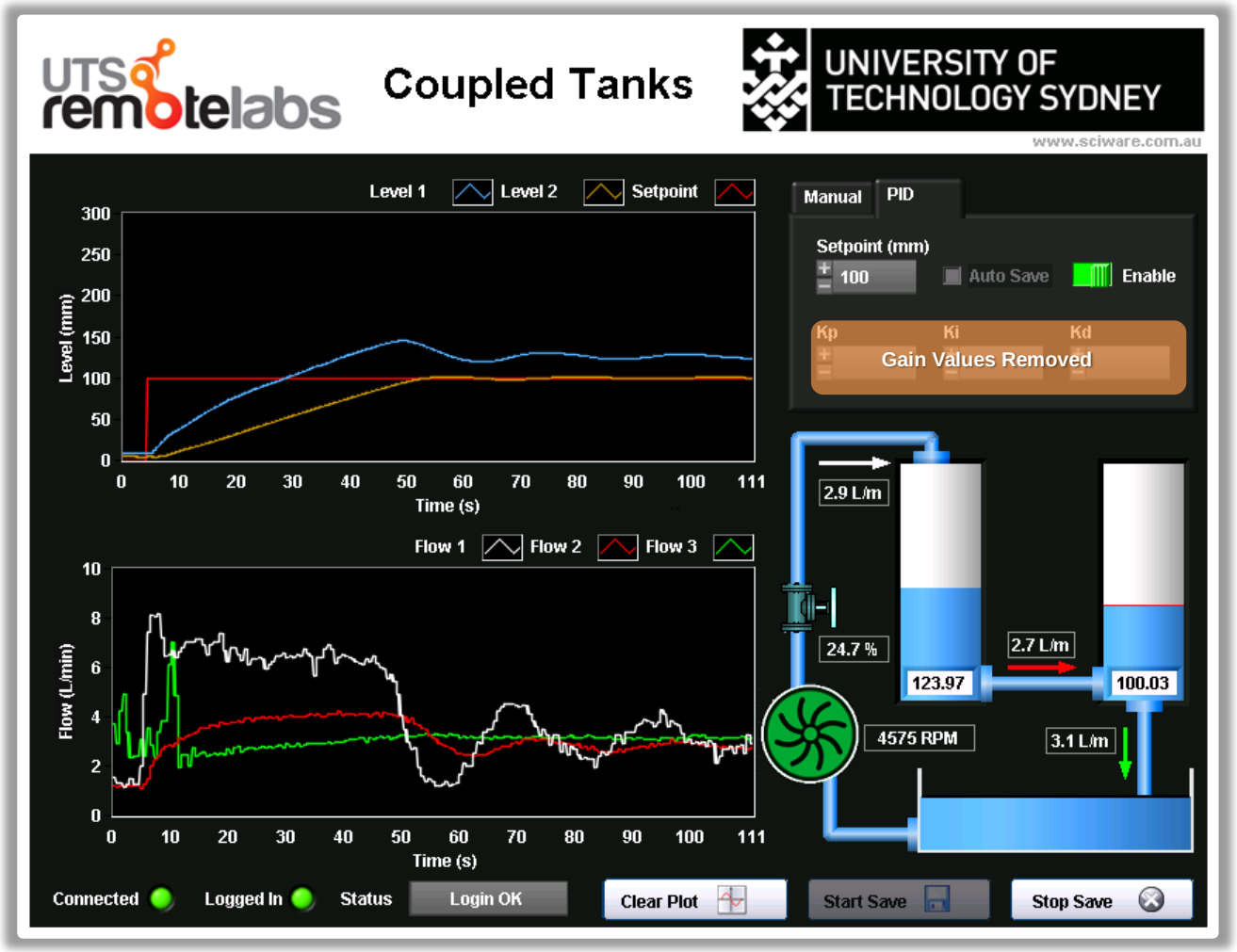
The Coupled Tanks Generation II Rig has two operating modes. The second is Closed Loop (PID) mode whereby the user enters a level setpoint for the secondary tank and the PID controller coefficients they wish to use.

4.2.1 Setpoint & PID Constants

By entering a setpoint and PID constants calculated from a model of the tank system or from an on-line response test, the coupled tanks system will be able to perform closed-loop control.

In this mode, the system monitors the level in the secondary tank and automatically adjusts the valve position and consequently the inlet flow rate on the fly (according to the PID constants set). As a result, extremely accurate setpoints can be reached (typically 0.1 mm intervals with maintenance within ± 0.1 mm).

It is up to the user to elect values that will render an appropriate response, i.e. targeting the fastest response time, minimum overshoot, etc.



Above: The system undertaking PID control for a setpoint of 125 mm. Note the accuracy achieved.

4.3 Switching Between Control Modes

The user can switch between control modes at any time. If you switch from Open Loop to Closed Loop, the current level in Tank 2 will be used as the setpoint. If you switch from Closed Loop to Open Loop, the current valve position will be used as the desired valve position.

Note that in PID mode, the PID control will not operate until you click the “enable” button so that it turns green. If the button is not enabled, the valve will be set to 0% and consequently the tanks will drain to their minimum operating level.

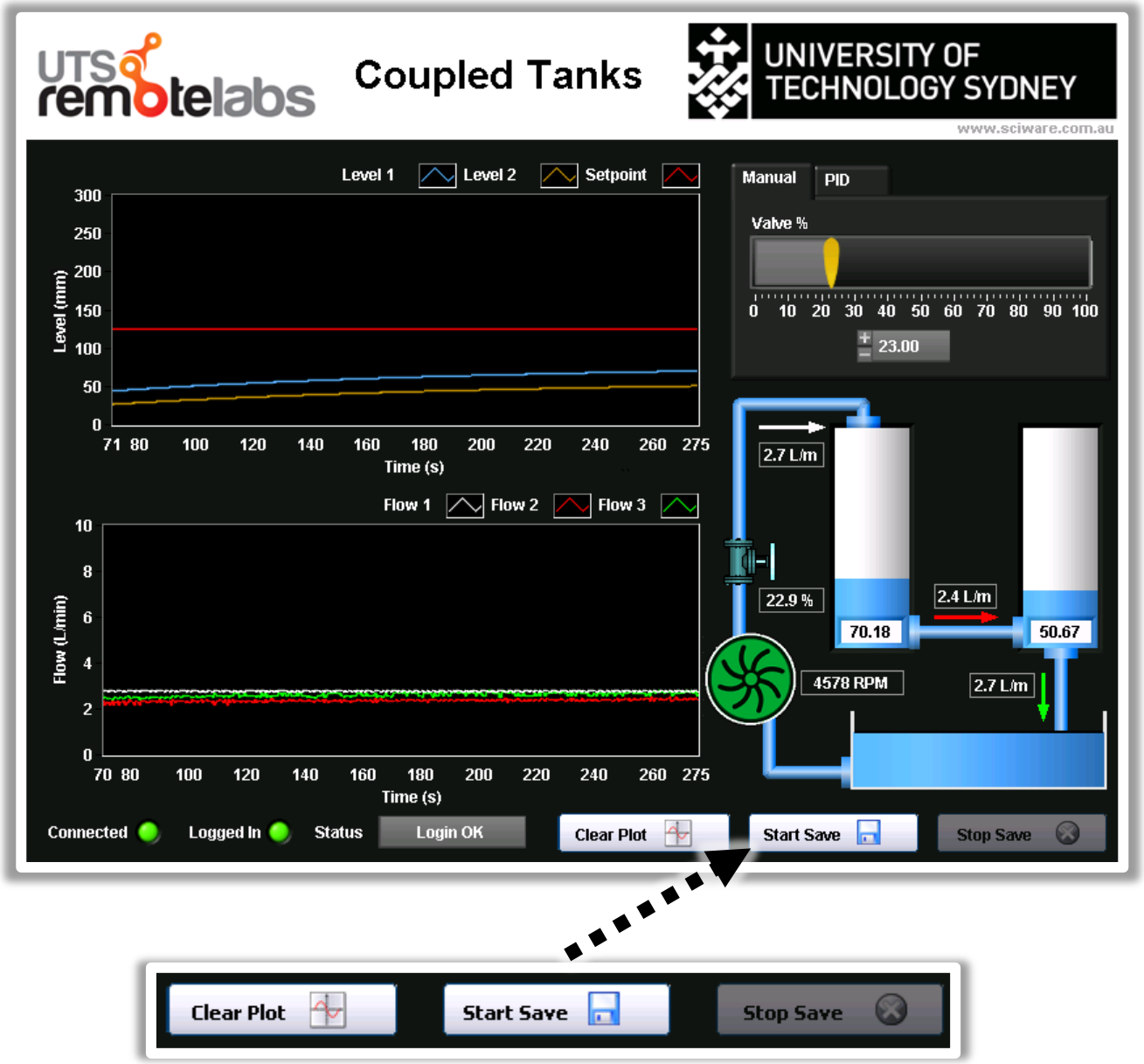
5 Rig Data Acquisition

Users are able to save sensor data for water levels, flow rates and valve position for later analysis in programs like Microsoft Excel or MATLAB. Please be aware of the various acquisition procedures depending on which mode you are operating the Rig in.

5.1 Saving Data - Manual Mode

In manual mode - sensor data can be saved whilst your session and the rig control software is active by **clicking the "Start Save" button**. Data will be recorded and saved to a tab-delimited text (.txt) file at 0.1 second intervals.

When you have completed your experiment or recorded the appropriate data, be sure to **click the "Stop Save" button.**

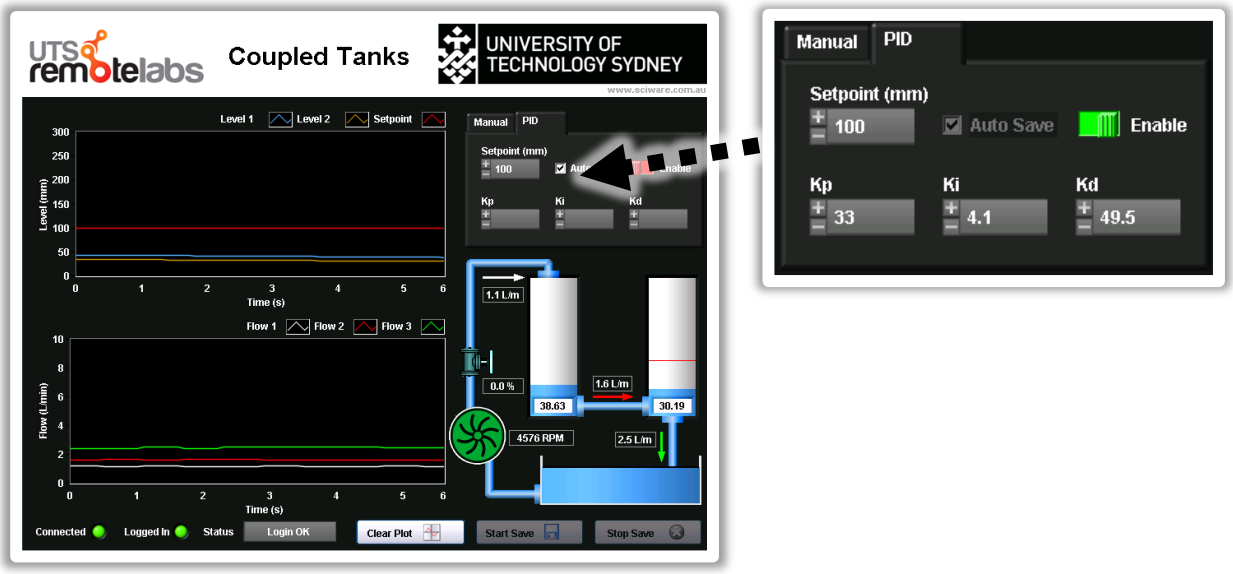


5.2 Saving Data - PID Mode

When the rig is operating in PID mode, you can choose to save data in an automated fashion so that you do not have any unwanted data and/or so you don't miss critical timing information (system response time, etc).

To do this – click the checkbox next to the "Auto Save" label. Data will begin to be saved when PID control is enabled. Data will stop being saved as soon as PID control is disabled.

Alternatively you can still use the manual start and stop save buttons – however note that they will be disabled when Auto Save is active.



5.3 Saved Data Format

Data is saved to a tab-delimited text (.txt) file at 0.1 second intervals. The data is divided up into columns, with the column order being:

Time (s)	*Kp*	*Ki*	*Kd*	*Setpoint (mm)*	*Valve %*	*Tank 1 Level (mm)*	*Tank 2 Level (mm)*	*Flow 1 (L/min)*	*Flow 2 (L/min)*	*Flow 3 (L/min)*	*Pump (RPM)*

5.4 Clearing Data Plots

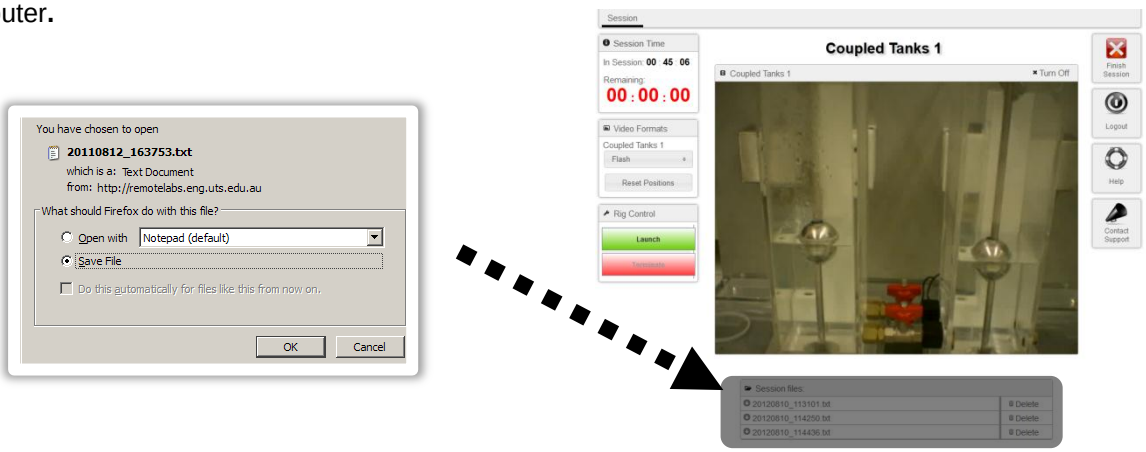
Plots of data recorded in the rig control software can be cleared at any time by clicking the "Clear Plot" button. This will clear all plots and reset the time counter back to zero, meaning that you can repeat an experiment or mark times at different points in the experiment.

5.5 Downloading Saved Data

As noted, any saved/exported data is saved to a tab-delimited text (.txt) file. This/these file(s) can be retrieved during or after the rig session. Please follow the processes outlined below for each scenario.

5.5.1 During a Rig Session

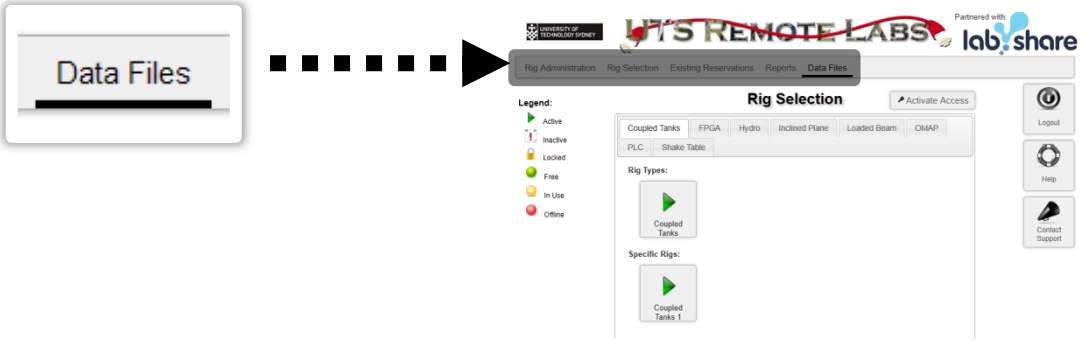
If you wish to download your data during a rig session, go to the UTS Remote Labs website window you used to launch the rig control software. On this page, there will be a "Session Files" heading – with a list of all saved text files. **Click the text file title** *(e.g. 20110812_163753.txt)* to download & save the file to your computer**.**



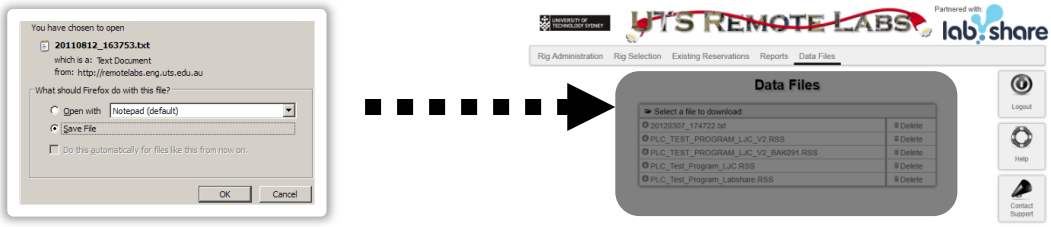
After clicking the text file title, a browser-specific download window should appear - be sure to click "**Save File**" or similar in this window to save the file in an appropriate location on your computer.

5.5.2 After a Rig Session

If you have completed a rig session previously, and saved data, you are able to retrieve the saved files by **clicking the** "**Data Files**" **heading** on the UTS Remote Labs website.



A list of previously saved data files should appear, to download & save the file to your computer, **click the text file title** *(e.g. 20110812_163753.txt)*.



After clicking the text file title, a browser-specific download window should appear - be sure to click "**Save File**" or similar in this window to save the file in an appropriate location on your computer.

6 FAQ & Troubleshooting

6.1 Hardware Limitations

The following hardware limitations apply to the rig – care should be taken to avoid mistaking real phenomena as faults and the limitations should be observed when selecting the operating parameters for the rig.

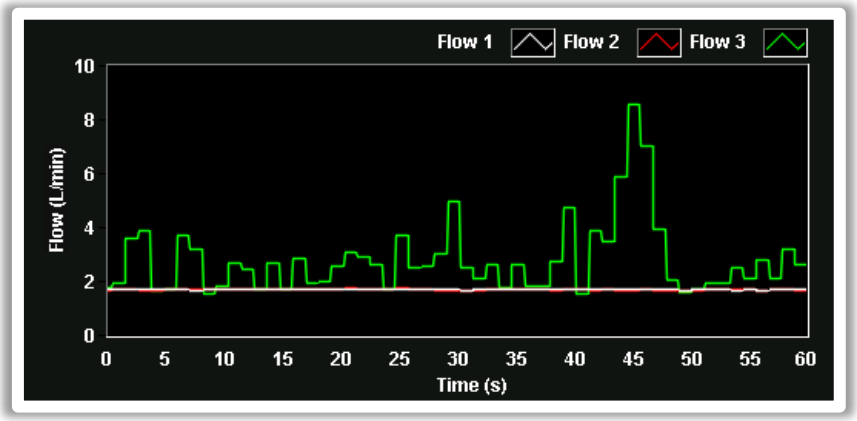
6.1.1 Inlet Flow Rate / Pump Continuously On / Valve Minimum Setting

You may notice that the pump can never be switched off and that water is always flowing into the tank, even when the valve position is set at the minimum possible (0%). A design decision was made to avoid startup lag of the pump complicating the experiment.

As a result – the pump is always on and its flow rate is modulated by the valve. In order to avoid damaging the pump – a minimum flow rate of approximately 1.0 L/min was deemed necessary – with this being achieved when the valve position is set at the minimum possible value of 0%.

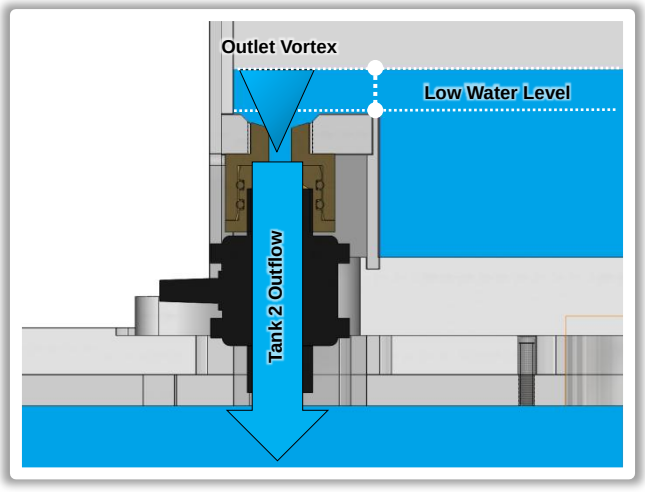
6.1.2 Outlet Flow Meter & Low Water Level

When the water level in Tank 2 is very low, the flow meter readings for the outlet may appear very high and there may appear to be significant changes in the flow rate. These readings do not reflect the actual flow rate through the outlet and occur as a result of the operating principle of the flow meters.



Above: Flow Meter Data Plot showing incorrect outlet flow rate due to vortex formation.

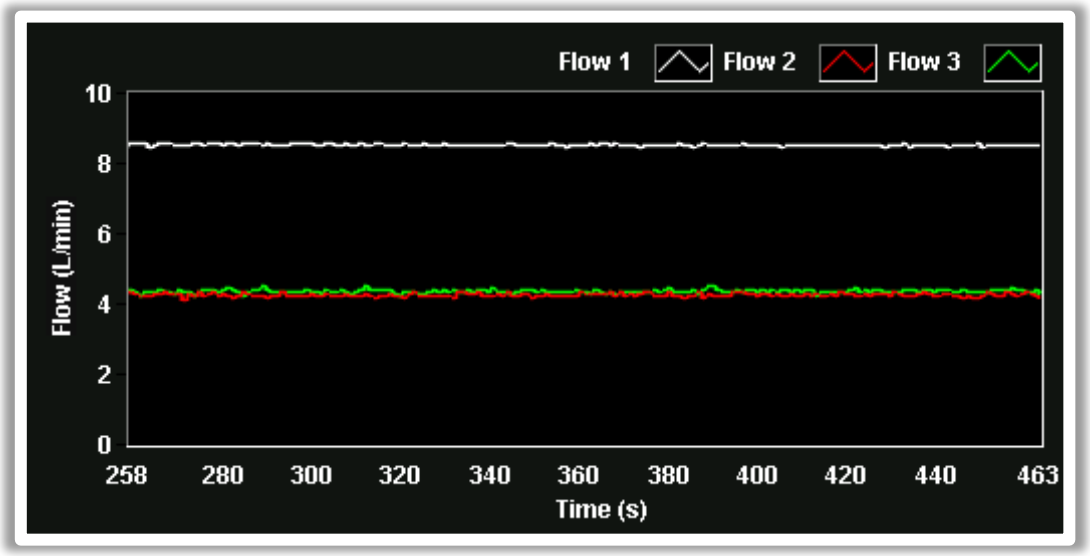
At levels below approximately 10 mm in Tank 2, a vortex forms and air is ingested into the tank outlet and accordingly the outlet flow meter. This causes inaccurate readings to be observed as the operating principle of the flow meter depends on the impeller and flow meter cavity being saturated entirely with water.



Above: Simplified diagram of outlet behaviour at low water levels.

6.1.1 Flow Meter Signals

The signals from the flow meters may appear to be quite noisy– this is however not noise but an artefact from the way the flow meters generate their signal and can be viewed as a “quantisation” of the signal.



Above: Flow Meter Data Plot showing signal artefacts which may be mistaken for noise.

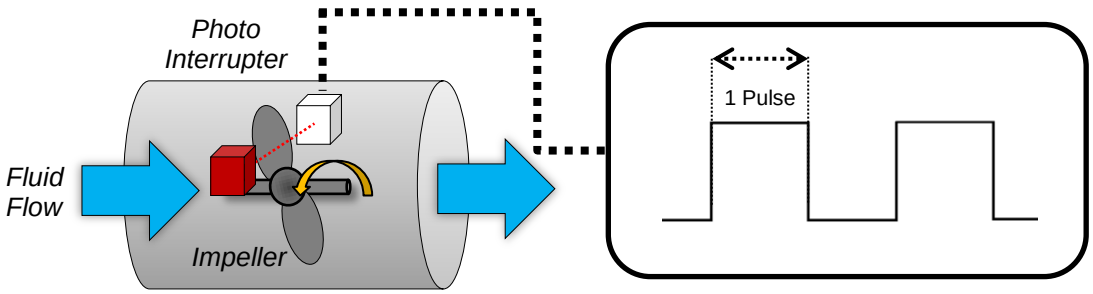
The units have a K-Factor of 752 pulses per litre. The data from the flow sensors is acquired by counting the number of pulses during the acquisition window. Currently the acquisition window is set to 2 Hz so as to allow a reasonable update frequency on the flow meter data plot.

When the flow rate is, for example, 1.0 Litre per minute (0.0167 L/s) one would expect 752 pulses per minute (12.53 pulses per second). Since the acquisition window is 2 times per second (2 Hz), we would expect to count 6.265 pulses.

However, the flow meters generate their pulses through the use of a photo interrupter – an electromechanical method. Since we count the full number of pulses during the acquisition window (effectively rounding down to the nearest pulse each time) we would thus only count 6 pulses.

Small variations in the flow rate can thus have an effect on the data displayed. For 6 pulses, when the value is converted into a flow rate using the K-Factor, we arrive at 0.957 L/min (0.0159 L/s), approximately 4% lower than the true flow rate. Resolution at this flow rate is thus ± 20%.

The good news is that as the flow rate increases, the error due to this rounding down becomes smaller. At 10 Litres per minute the error is only 1.1% of the true flow rate. Resolution at this flow rate is thus ± 2%.

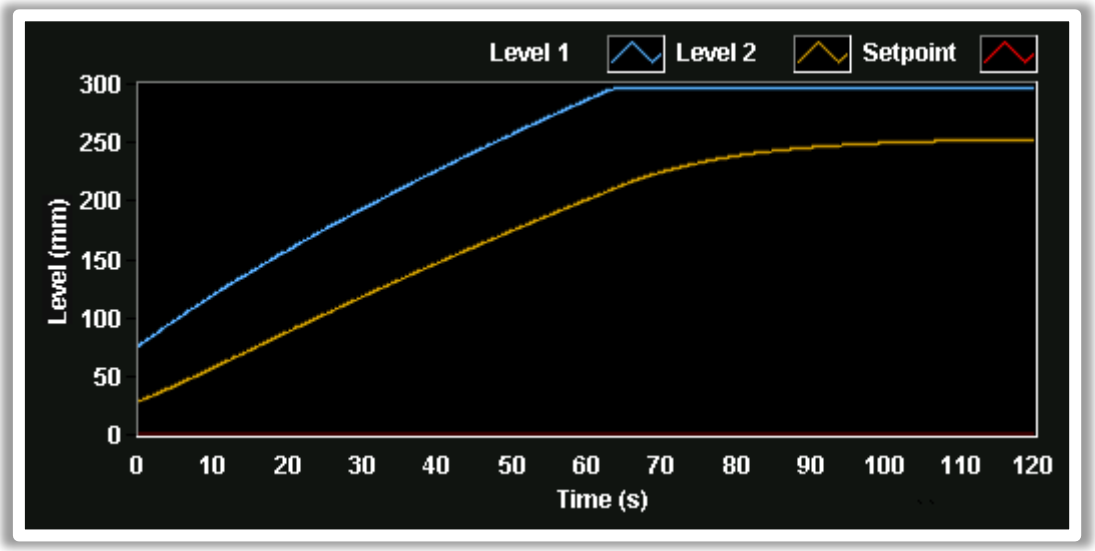


Above: Simplified diagram of how the flow meters generate their output signal.

6.1.2 Overflow State

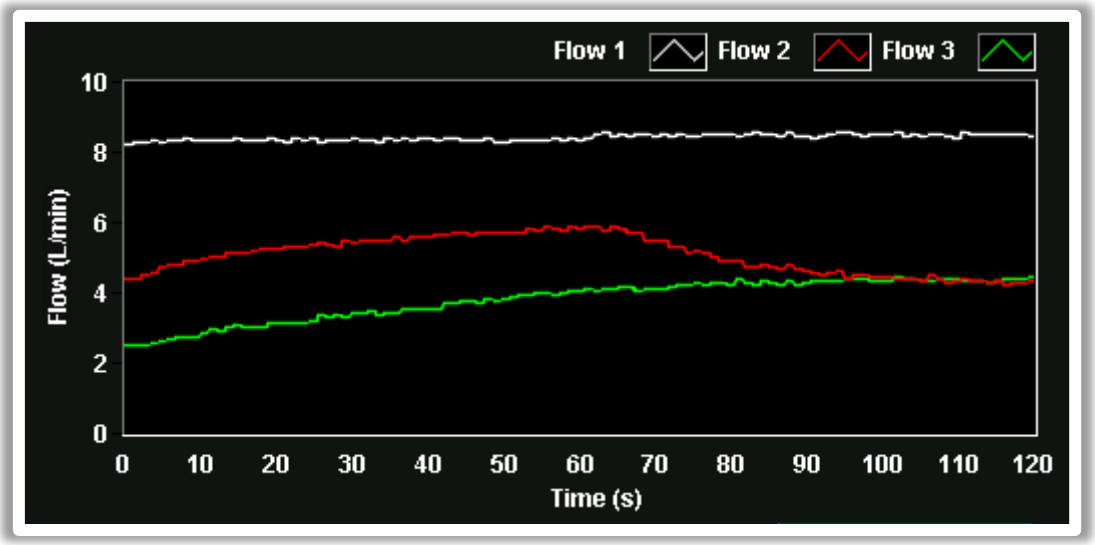
When the inlet flow rate to Tank 1 is set too high in Open Loop control mode, it is possible to reach an overflow state – whereby the water level in Tank 1 rises and reaches a stagnation point as the inter-tank coupling valve flow rate is not high enough to transfer the water to Tank 2. As a result, the water level in Tank 1 reaches a maximum of approximately 295 mm (± 2.5 mm) and spills over into the overflow section of the tank.

When this occurs, the user will see a sudden transition to a continuous level on the level data plot and additionally the level readout for Tank 1 will show approximately 295 mm. Note that Tank 2 can never reach overflow due to the pressure drop (ΔP) through the inter-tank valves, the maximum level for Tank 2 is approximately 255 mm.



Above: Tank 1 reaching the overflow point of approximately 295 mm. Note that Tank 2 can never reach overflow due to the pressure drop (ΔP) through the inter-tank valves.

It is important to note that once the tank has reached overflow, any data recorded for certain modelling techniques – e.g. step response - is invalid as the true level that would be reached cannot be measured.



Above: The inter-tank flow rate (red) dropping as the level in Tank 2 attempts to match that of Tank 1.

6.1.3 Magnetic Float Bobbing & Disturbance

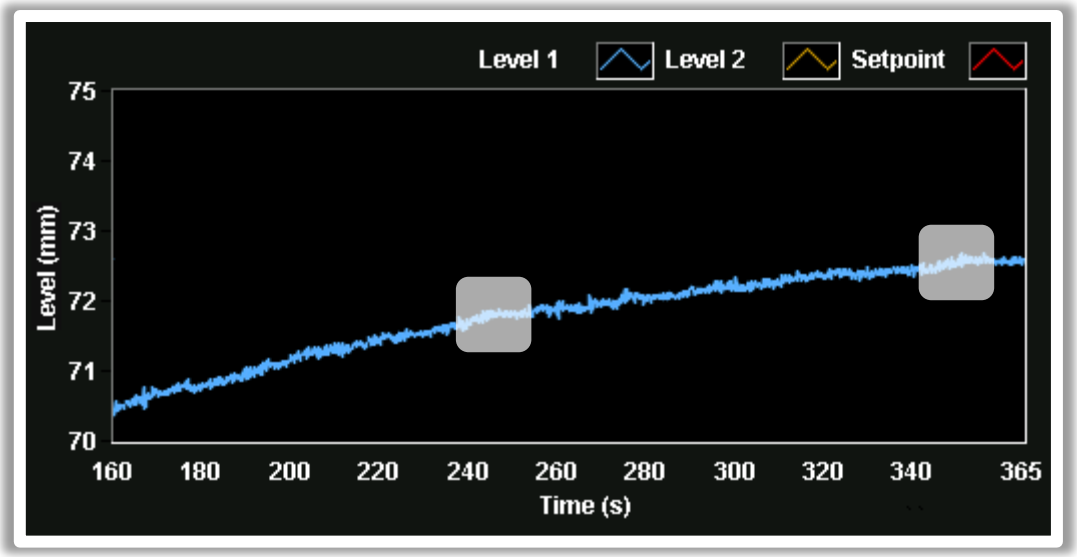
When looking closely at the level sensor data for Tank 1 – it is possible to see small fluctuations in the level. There are two reasons for this – the first is due to the way the water flows into the tank and the second is due to the way the magnetic floats are coupled to the level sensors.

The water flow into the tanks is de-coupled except at the very upper reaches of the tank level (close to the overflow level of 295 mm). This means that the flow stream exists in free air and reaches the water surface due to the effect of gravity.

When the flow stream hits the water surface, it thus makes a disturbance – creating small variations in the water level recorded by the level sensors.

Additional variations in the water level are seen by the level sensors due to the magnetic floats having a significantly larger internal bore diameter when compared to the outer diameter of the level sensors. As a result, in a steady state condition – the floats move around with the water current in the tank.

These variations are very small (sub-millimetre) and should not impact any typical experiments undertaken on the rigs.

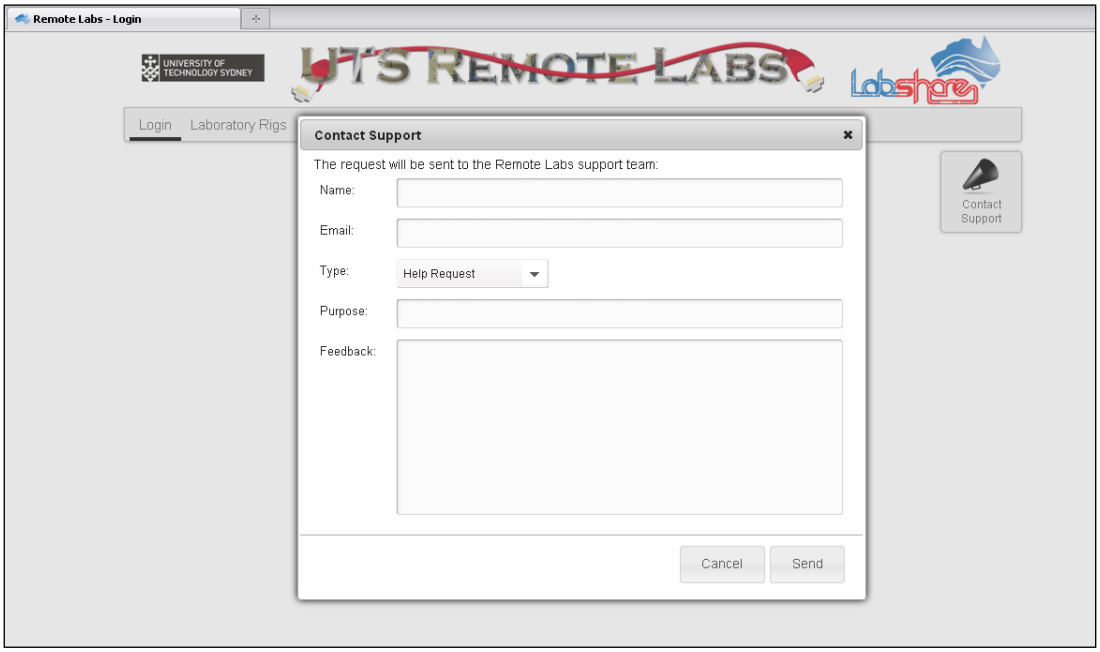


Above: Small variations (white) in the recorded water level due to surface disturbance and bobbing of the magnetic float.

6.2 Contacting Support

Any questions regarding the nature of assessment tasks should initially be directed to the relevant academic. If the user encounters any difficulties during the course of using the rigs, the "**Contact Support**" button should be used to request assistance and report an incident.

The following popup will appear – please enter your name and a valid email address, followed by a category from the "Type" drop down list.



You may then enter a brief statement regarding the nature of the request in the "Purpose" field. Be sure to enter as detailed a description as possible of the incident in the "Feedback" field.

6.3 Providing Feedback

Users are strongly encouraged to leave feedback and comments of their experience with the rigs to help improve the system, as well as any suggestions for additional features to be included in the future.

For any enquires or assistance, contact the Labshare helpdesk at:

helpdesk@labshare.edu.au